Quality Engineering Methodology in Covid-19 Systems Design and Improvement

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1.0 Introduction

We discuss here the role of *Quality Engineering* (QE), including *reliability, logistics, industrial and operations research statistics-based* methods, in improving health care systems dealing with the Covid-19 Pandemic. In particular, we employ QE methods in the analysis of four important systems: *Opening of the Economy*, *Locking Down of the Economy*, *Re-Opening of Schools*, and *Vaccine Rollout*. These statistics-based methodologies are effective in designing, implementing, streamlining and making Covid-19 related systems operations easier to manage and control.

Our paper pursues *three objectives*. First, to *examine QE methodologies* in general. Secondly, to *provide practical examples* of the implementation of QE methods, so Public Health and Medical researchers can become aware of their power to improve operations. Finally, to *showcase several applications*, developed by MFE634 https://web.cortland.edu/matresearch/MFE634SylS17.pdf (our graduate Syracuse University course). These students, under our guidance, developed four Covid-19 related projects that will illustrate the present discussion. MFE634 students are trained in analyzing real life problems (https://web.cortland.edu/matresearch/PastProjectTopics.pdf) and may apply for positions in Public Health institutions that seek young engineers with QE skills.

In April of 2020, we wrote https://web.cortland.edu/matresearch/Covid-19Proposal2020.pdf, a *proposal to the research community*. We then started writing, distributing and *hanging in web* forums (ResearchGate, LinkedIn, etc.), *our research papers*. They are listed and *summarized in*: https://www.researchgate.net/publication/349008991_Commented_Summary_of_a_Year_of_Work_in_Covid-19_Statistical_Modeling The material was well-received, as per LinkedIn, Research Gate hits: https://web.cortland.edu/matresearch/SELECTEDREADINGSRESEARCHGATE.pdf

The current *report analyzes problems* arisen in the four, above-mentioned systems. By *using QE* approaches, and by implementing QE *improvement methodologies* in such systems, we may be able to detect, and *avoid or minimize system problems*, *identifying* and *correcting glitches,* or *providing mitigating actions* where such difficulties are unavoidable. As result, said systems and operations will become more effective, reliable and available, and logistics work, more efficient.

2.0 Basic Quality Engineering Analysis Tools

In the present section, several *Basic and Sophisticated QE tools* will be both overviewed and illustrated https://web.cortland.edu/matresearch/QualEngGralMfe.pdf. Then, tools will be implemented in the four Covid-19 related projects that will be reviewed here.

When starting a *Quality Engineering project*, we first implement *an assessment analysis*, to have a sense of the state of the problem(s). We gather a group of subject-matter experts, develop a *Brainstorming* session with our *project objective as ultimate goal*, and examine the Cost of Poor Quality (*COPQ*). Some costs are evident, but *other costs are hidden* and difficult to identify. For example, lack of appropriate vaccine storage may produce a number of spoiled vaccines, and will produce a number of non-vaccinated persons. Some of these may become infected, hospitalized, and die, incurring in medical costs. Some such hidden costs may not be always readily evident.

We group these ideas through an *Affinity analysis*, and create a *Fishbone Chart* showing how the *final overall objective* (e.g., reducing infection levels) *is affected by said chart branches* (factors social distancing, vaccination, mask wearing). *This qualitative chart* will eventually become the *core of* Regression, ANOVA, Design of Experiments and other *key statistical analyses*.

We continue *collecting information*, through interviews of different system elements. We thus need to create *organization trees*, *system flowcharts*, etc. to determine whom to interview, how the system works, what are possible bottlenecks, mis-steps, etc. Some of these charts will then become more sophisticated schemes (e.g., flowcharts may become *Value Stream Maps (VSM)*, whereby idle steps or bottlenecks may be identified). Information obtained from the interviews may help develop the *Quality Function Deployment (*QFD*) Matrix Cascade*, whereby the *needs of the customers* will be addressed and resolved by technical elements.

We face basically *two situations*: either there is *a working system* that needs improvement, *or* there is the *intention of building such system*, which must first be designed. *Six Sigma* (DMAIC or DFSS) are two well-suited methodologies. Six Sigma requires a *Champion*, as we will *step on a lot of toes*, and disturb many *established interests*. The Champion, a high-level officer, will ensure that our questions are answered, and that our instructions are followed. If the system is designed, Failure Modes and Failure Trees analyses (*FMEA/FTA*) can be implemented, to help identify problems (https://web.cortland.edu/matresearch/FMEA&FTASumaryS2017.pdf), their causes, consequences, and implement corrective actions. We discuss more on this, in Section 4.0.

Before we start measuring system variables, a *Measurement Systems Analysis (*MSA) must be undertaken, to ensure that we are not introducing errors during the measurement process. After the system is improved, we apply *Statistical Process Control (*SPC) tools to verify that it keeps operating correctly. When the system deviates from correct operation, we must stop it, identify and correct the problem(s) disturbing the correct operation, and then restart it.

QE methods (https://web.cortland.edu/matresearch/NEQCPaperOct2018.pdf) discussed in the following pages are just some of the QE most important tools. In the bibliography, at the end of this paper, readers will find further references that will help them better understand our work.

3.0 Applications via Some Student Group Projects

In this section we employ *QE and other statistics-based engineering methods* in the assessment and improvement of *four important Covid-19 problems*. After discussion of the methods and its implementation *we present, as illustration*, four *MFE634 student group PPTs*. Said PPTs were developed, under our supervision, for their MFE634 course final projects.

3.1 Quality Engineering Study for the Efficient Reopening of the Economy

Shutting down the economy is always a risky and unpopular measure of last resource. It has been *heavily criticized as unwarranted, inefficient, worse than the problem*, etc. However, *in the cases where it has been applied*, where Covid-19 infection and death rates were extremely high, caused by a new problem, that few if any understood well, *Lockdowns managed to improve conditions*.

Once the Economic *Lock Down has achieved a flattening of the Covid-19 Infection curve* (thus *avoiding overwhelming the health care system*, its main objective) then it is time to *prepare the* ollege*Reopening of the Economy*. However, this *needs to be done carefully*, so Infection Rates don't start increasing and we need to return to a Lockdown. An analysis of Covid-19 infection rates and of possible social factors that help lowering them, by counties and regions, are discussed in *Design of Experiments in Identification of Factors impacting Community Spread of Covid-19*
https://www.researchgate.net/publication/341532612_Example_of_a_DOE_Application_to_Coronavarius_Data_Analysis Such types of analyses may be used to guide the Reopening process.

We first *Brainstorm*, using subject-matter experts, to *identify the key factors* that can help control Infection Rate. Then, based on data analyses as the DOE mentioned in the above paragraph, we establish some *selection rules and a hierarchy of industries*, and decide which ones will reopen first. *Not all industries should open simultaneously*. For example, the *strategic industries* should open first; secondly, the *support industries*; and then, those industries able to operate under the established *safety rules* (e.g., social distancing, masks, testing). *In addition*, we need others that are necessary for the *logistics support* of those returning to work (e.g., transportation, dining, schools, day cares) so workers do not leave their children alone, or are forced to stay, at home).

Then, *reopening* a company that has been closed for some time *is not easy*. It may *require fixing or tuning* up some or all of its facilities and *restarting their supply chains*. *Technicians* (e.g., mechanics, electricians) and their working materials and tools, should also be *available*.

To maintain the levels of Infection within acceptable ranges, these must be *constantly monitored* via *SPC* procedures (https://web.cortland.edu/matresearch/AplicatSPCtoCovid19MFE2020.pdf) located at geographical (e.g., city, county) and business or industry spots. Such level of testing requires setting up *sufficient processing facilities* able *to handle* this operation, and to establish *rules, if infections rise*. For, when some geographical zone, or site goes out of Control, it needs to *shut it down* totally or partially, *until causes of such infection* level are *determined and removed*.

We present a Student Group QE Powerpoint applied to the efficient Re-opening of the Economy (https://web.cortland.edu/matresearch/EconomyReopeningG2.pdf). They start by *Brainstorming* the problem and finding areas (factors) and sub-areas (levels) that affect the overall objective (reopening) measured through appropriate Performance Measures (PM) such as number of jobs.

With this information students create a *qualitative Ishikawa* (or fishbone) chart, which *eventually* serves as framework for *quantitative statistical procedures* (e.g., regression, DOE, ANOVA).

Based on such discussions, students *start a quality assessment* by implementing the *COPQ* (*Cost of Poor Quality)* analysis: f*our problem categories*: *internal, external, appraisal and prevention*. In the case of reopening a restaurant, an example of *internal* problem would be not to adequately separate the dining tables; an example of *external* includes enabling customer contagion by lack of adequate social distancing space; example of *prevention* would be, providing staff with basic training, PPEs and cleaning materials; an example of *appraisal* includes the periodical employee testing, and the taking of temperature and inquiring health information from incoming customers.

Such information material comes from *interviewing* both subject-matter experts and customers, to find out what are the *key issues involved* in the operation of the system, which should first have been flowcharted in detail. The *process flowchart* eventually yields the *Value Stream Map*, (VSM) which helps determine *bottlenecks*, *non-value-added steps* and other features that can then be modified, substituted or deleted from the *system operation*, improving it substantially.

There is a final section in the student PPT that deals with the *Process Capability* (PC), which is implemented using *daily infection rate*, a quantitative variable. Assume that the public health has determined that a *safe infection index lies roughly at 5%.* Then, restaurant specialists determine that less than 3% is economically unfeasible, and over 7%, unsafe. Those become the *lower and upper specification limits*. We let the *stable system* (restaurant) operate and measure the average restaurant daily infection rate, for a month. A set of calculations, done by PC software, shows the PC Graphs in the student PPT. The PC graph for Group 4 is acceptable, for it falls within the two specification limits. PC for Group 8 is unacceptable, as part of it falls beyond the upper limit.

Result indicates that a project must be undertaken to improve this PC. After its implementation PC must again be measured, to verify that the project has achieved its objectives (before/after).

Before collecting any data (or measuring), we should implement an *MSA (Measuring Systems Analysis*) to determine if measurements taken include undesired elements, such as *operator or gage biases*. *Gage R&R* analyses are implemented to detect these problems. If an overwhelming percent of measurements (say 98% or above) come from the system and only a small percentage (say 2% or less) come from operator and/or gage bias, MSA is OK. Otherwise, we must first fix the measurement system, retest it, and if accepted, then we can safely measure variables.

3.2 Quality Engineering Study for the Efficient Lock Down of the Economy

Lock Down is critical and *affects most people directly* (jobs loss), or indirectly (loss of services). It is justified because the *consequences of a high level of infection* (e.g., overloaded health care facilities, increases in death rates), are *much more costly* than the consequences of a Lock Down (e.g., unemployment). In this case, *providing subsidies* to those economically affected is a very *helpful and efficient measure*. Subsidies should be *well-calibrated, so they do not foster inflation or become a disincentive* for people to go back to work, once the Lock Down ends.

Just as with the Opening, *not all industries* and businesses *should shut down simultaneously*. A *ranking* of industry types should be *established*. And those businesses that *shut down*, should follow a *process* that *allows them to restart efficiently* once the infection rates decrease. The difference between good and a bad engineers is that, the former *incorporates* in their devices design the *necessary specifications* to disassemble them, if need be. Thence, *precautions should be taken to mothball all operations* so their components do not deteriorate, establishing periodic inspections, maintenance, etc. and keeping a skeleton crew to oversee such activities.

Which regions should be promptly Locked Down and which can still wait, may be established by statistical analysis: *More on Principal Components and Discriminant Analysis of Covid-19 data* https://www.researchgate.net/publication/342154667_More_on_Applying_Principal_Components_Discrimination_Analysis_to_Covid-19 provides some examples of such type of analyses

Next, we present another Student Group QE *Powerpoint*, applied to the efficient Lock Down of the Economy (https://web.cortland.edu/matresearch/EconomyLockDownG1.pdf). As customary, students begin with *Brainstorming* the problem, and finding areas (factors) and sub-areas (levels) that affect overall objective (Lock Down) measured through some appropriate PM such as total number of jobs lost. Brainstorming is *followed by* an *Affinity diagram* and its *Ishikawa chart*, that use a *quantitative response* (infection rate). Such variable expresses the current state of the objective (lowering infection rate), as well as key factors that impact such objective.

Just as before, the operation of the *process is flowcharted*, to better understand how it flows in time. An *organizational tree* helps identify *key people* to *interview*, to determine the principal elements that impact this process, which are then included in the *COPQ* analysis.

The *assessment* includes the *identification of* instances within the *four categories of the COPQ*. It is very important for the improvement project to establish these *instances and associated costs*. For improvement projects are quite costly, and *management* will be *reluctant to implement* any *change unless* it is convinced that, *not doing so will be even more expensive*. For example, the cost of stopping operations for enterprises is costly. But the cost of the virus spreading through the entire country without control, will cause a much longer and expensive lock down.

Student PPT ends with initial *quantitative analyses between* two college *groups* (engineering and humanities) *to determine whether* there has been a *difference* in infection levels. *Whenever more than one cohort* is involved (e.g., *cities, counties, states, industries*) it is *important to examine whether groups are similar* (and can be combined) *or different* (and should be kept separate).

3.3 Quality Engineering Study for Efficiently Re-Opening Schools

We have seen how many, if not *most schools* (at all levels of learning), have moved to *Distance Learning* (e.g., Zoom, Internet) modes. Many students, especially *younger ones, do not perform well* under these learning modes. There is also the *lack of socialization*, a key issue for younger students (e.g., Pre-K, Kindergarten, first three grades). Finally, there is *the parental issue*: where do they leave their children when *they go back to work*, if schools do not reopen?

To reopen school systems, it is necessary to ensure *a safe environment for students* as well as for the *school staff*. It is *difficult* to accomplish this *through social distancing* (masks, testing, etc.) *without affecting the entire school operation* (less classroom space and increased complexity of activities such as lunch, due to social distancing; age and comorbidities endanger some school staff). The *most efficient way* to ensure a safe environment is, thence, *through vaccination*.

There are *several key issues* that must be taken into consideration. Schools are embedded in a region, a county, or state. Thence, *the prevalence of Covid-19* (i.e., existing infection rate) must show that there is a safe environment for school operation, as children, staff, etc. live in such a region. Also important, is the consideration of *support systems*: transportation, dining, internet services and their supply chains (mechanics, garages, shops, warehouses, computer support etc.)

There are several ways to approach this problem. We have analyzed this issue using stochastic processes in: *A Markov Chain to study the problem of Re-opening Colleges under Covid-19:* (https://www.researchgate.net/publication/343825461_A_Markov_Model_to_Study_College_Re-opening_Under_Covid-19 *QE methods* can also be successfully *applied to designing or to fixing* the problems of a school *system reopening project*.

We present a Student Group QE *Powerpoint* applied to efficiently Reopening a school system (https://web.cortland.edu/matresearch/SchoolReopeningG4.pdf). They start by *Brainstorming* the problem and finding areas (factors) and sub-areas(levels) that affect the overall project objective (reopening the system) measured through appropriate PM such as number of students served.

The usual *Affinity diagram and Ishikawa chart* are built from the information gained from open discussions in the Brainstorming exercise. A *Process flowchart* is built, to better understand the *system flow*, and plans and contingency measures are proposed to mitigate or avoid problems.

COPQ categories are analyzed in detail. For example, in testing these categories are: internal, lack of technology, materials or technicians; external, lack of sufficient testing due to existence of some of the aforementioned issues; appraisal includes the training of testing personnel; and prevention includes *back-up strategies* to cover the absences of testing technicians or materials. COPQ will help convince management in investing time, effort and resources into the activities recommended by the improvement team, which are always expensive. Management will invest, when not doing so will end up costing them much more time, effort and resources.

Assessment continues with *interviews of key subject matter experts*, to determine other elements that will eventually become part of the project data collection or experimentation. *Initially, data* will be *analyzed graphically* and through elementary methods. Once *key variables are identified,* data will be treated through more sophisticated statistical methods, and will be submitted to *more complex models,* which will be overviewed *in Section 4.0: Advanced Procedures*.

3.4 Quality Engineering Study for the Efficient Roll-Out of the Covid-19Vaccine

Of all four topics, this is the one that has caused a major concern. *Rollout*, in December of 2020, was *poorly organized*. And there are *important causes* for this occurrence, many of which could have been *identified and addressed*, in an *in-depth initial assessment and prototyping* exercise.

The *original conception* of the vaccine rollout task was *not efficient*. The Federal Government provided the vaccines to the States. And these were then supposed to distribute them further, to the people. *An efficient task* requires that *vaccines flow directly, from the manufacturer's site, to people's arms*. Anything else would interfere (as it actually did) with the vaccine rollout process.

A *key failure*, that may be shared among all above-mentioned three projects, was *a deficiency in Prototyping*. Good Engineers *first design* their products. *Then*, they *try out their designs on some prototype*, physical or simulated, which is used *to compare and improve the original designs*, to assess their different levels of performance, and to identify and correct the problems they find, before the product is released. Had vaccine rollout *designs been first tried and compared in a small state or county*, or via simulation, some *problems* that occurred during the December 2020 Vaccine Rollout *could have been identified, addressed and corrected before the Rollout* began.

Another key problem in vaccine rollout was *failure to establish and maintain* a vaccination *rule*. At the start of vaccination, public health and key personnel (police, fire department, etc.) as well as nursing home residents, were prioritized. But soon, due to political pressure, additional groups were included, leaving independently living seniors, out. *Strict, unwavering rules for vaccinating* the population, *according to decreasing age*, possibly *using the local drugstore networks*, that most people can easily reach, *instead of creating few and massive vaccination centers*, in areas *requiring transportation*, would have perhaps been more efficient, particularly for the elderly, the poor and the disabled, many of whom had difficulties, or were unable, to access them. Both of these alternatives should have been tried, assessed and compared first, via some prototype. Then, the best of these options could have been selected, before full rollout was implemented.

There are several ways to approach immunization. We analyzed this problem using stochastic processes, in: *A Markov Model to Assess Covid-19 Vaccine Herd Immunization Patterns* *https://www.researchgate.net/publication/347441411_A_Markov_Model_to_Assess_Covid-19_Vacine_Herd_Inmunization_Patterns* and using multivariate and regression analyses, in: *Logistic Regression/Discriminant Analysis Identifying key Covid Vaccine Clinical Trial Factors* https://www.researchgate.net/publication/346956247_Logistic_Regression_in_Factor_Identification_of_Covid-19_Vaccine_Clinical_Trials We also discussed clinical trial issues of vaccination in: *A Digression about Aspects of Clinical Trials for the new Vaccine against Covid-19* https://www.researchgate.net/publication/346305686_A_Digression_on_Covid-19_Vaccine_Clinical_Trials_and_its_Consequences and in *A Digression on Covid-19 Vaccine Rollout*: https://www.researchgate.net/publication/348607971_A_Digression_on_Covid-19_Vaccine_Rollout we discuss the urgent need for everybody to get vaccinated.

It is important to underline that *Covid-19 immunization can be obtained by vaccination, as well as infection*. Therefore, when considering *Herd Immunization*, we should add the *known number* of vaccinated persons plus the *unknown number* of infected persons, many of which never knew they had the virus because they were asymptomatic. The implication is that, to acquire the 70% level of population immunization needed for achieving *Herd Immunization*, less than the 70% population vaccination level is really sufficient (though we will never know exactly how much).

Then, since *Rollout is a system*, we need to *consider all support operations*. Vaccines need a low temperature: we need to consider *refrigerated transportation and storage* and their related back ups: *mechanics, spares, a Plan B in case of general failure* (it occurred in Houston, TX) etc. For vaccination centers: the *number of nurses and technicians*, including substitutes for absences and lunch/bathroom breaks, etc. Ensure a *stable flow of patients*: for *containers*, once opened, cannot be re-stored, and *unused doses are lost*. *In the Third World, Covid-19 vaccines are badly needed.*

QE methods can also be successfully applied to designing (or fixing problems of) a nation-wide vaccination rollout system. We present a Student Group QE *Powerpoint* applied to Rolling Out said vaccination system (https://web.cortland.edu/matresearch/VaccineRolloutG3.pdf).

Students start by *Brainstorming* the problem, finding *groups* that are *integrated in the Ishikawa chart* as branches (*factors*) and sub-areas (levels). These *affect the overall objective*, measured through an appropriate *variable or response* such as the *number of vaccinations achieved*.

Process Flowchart helps to *identify* potential *bottlenecks* and useless, *non-value-added steps,* as well as places where useful *data* can be *collected*. *COPQ* helps in identifying difficulties: in the transportation of vaccines, internal problem includes driver failure to identify gas and food stops; external problems include loss of time by drivers searching for suitable garages, mechanics and diners; appraisal includes the effort to measure the efficiency of transportation (percent of correct delivery, average time, percent delays etc.); prevention may include short training sessions for drivers, presenting potential problems and identifying possible solutions (e.g.; if breakdown in a specific area, there is a garage with mechanics in this location). A *tree for potential interviewees*, and questions for starting project assessments and for developing further ideas, including some graphical analyses (e.g., *Pareto Charts, scatterplots, histograms*) end the presentation.

4.0 Advanced Procedures

So far, we have reviewed the early stages of a *Quality Engineering project*. Essentially, these can be of two kinds. *Either the system exists*, but users an unhappy with its performance and want to improve it; or the *system does not exist* and *users want to design one*, as efficient as possible. *For the first case*, we use QE improvement methodologies such as *Lean (using Value Stream Maps*, VSM), *and Six Sigma* (DMAIC); for *the second case*, we use *Design for Six Sigma* (DFSS) and design methodologies such as *Quality Function Deployment* (QFD), and *matrix cascades* that translate user needs into technical and engineering solutions that efficiently provide for them.

Suppose we want to improve the Vaccine Rollout system, that is in place, but is not functioning efficiently. We can use *Lean*, or we can use *Six Sigma*, or a *combination*, in that order. Lean will require building a *VSM of the system process*, which will help identify ill-defined, incomplete, non-value added and bottleneck steps. VSM nodes (process steps) include parameters such as its reliability, mean time, variability, queue size, etc. For example, a VSM would show that vaccines are delivered to state authorities, instead of vaccination centers (their delivery is done, later, by the state authorities). Or it could show that vaccination centers have too many (or too few) staff, parking space, sufficient transportation, etc. Such problems should be investigated, the root cause identified, and then corrected. The *Lean result* is a streamlined system, with *fewer (or no) waste*.

Six Sigma looks into *variability of the process*. Highly variable processes are less efficient and difficult to manage. The *Define phase* consists in selecting the project (among several options) to work on, selecting the team, a “Champion” (i.e., a high-level officer). One must be included to enforce difficult decisions or obtaining sensitive information. Then, a project charter (results we will achieve). The *Measure phase* includes an initial MSA, assuring that data collected is good; a data collection plan, some tentative hypotheses, etc. Measuring and collecting data for time to deliver vaccines, variability, reliability of the shipments, are some examples. Places where such data will be collected and initial hypotheses. The *Analyze phase* we implement hypothesis tests, regressions, ANOVA, DOE, Process Capability and other statistical methods, with the collected data, and determine which factors, if any, affect the responses of interest, and how.

After an analysis of test results, a proposed *improvement process is selected* and *implemented* on some prototype, then assessed. As things have changed, a *second MSA* is required to validate the new measurements taken. *If prototype results are effective, then method is deployed full-scale*. Finally, the *Control phase* establishes the necessary *procedures and checks so the system does not return to its initial state*. For, new procedures and improvements may have stepped on some toes. And those affected by the changes will try reverting the system back to its previous state.

Lean and Six Sigma can be combined, implementing the former first, then the latter. The result, contributing the characteristics of these two methods, will produce a more efficient (lean), and less variable, system. *Lean-Six Sigma* improvement combination is *strongly recommended*.

Suppose now that we wanted *to create a new Vaccine Rollout system*. In this case we could use *DFSS, a variation of Six Sigma*, combined with *QFD and matrix cascade*. Its first three steps (*Define, Measure and Analyze*) are the *same as in Six Sigma*. The latter two are: *Design, Verify*.

In the *Design phase* we use the *QFD* matrix (also known as *House of Quality*). Here, we place as rows, the *customer requirements* (e.g., accessibility, short waiting times, parking). We place as columns the *proposed technical solutions* (e.g., selection of many small, local sites, such as drug stores, versus few large vaccination centers, such as stadiums). It would be optimal to *implement both solution designs in a prototype* and then carry out *statistical analyses to determine which* of is better -or if a combination (and in which order) *is more efficient*. The *Verify phase analyzes* in detail the *design validity* via an *FTA or an FMEA*, or via some *physical prototype*, or via running a *Discrete Event simulation model*, if experimentation on physical prototypes is not feasible.

A matrix cascade is a *sequence* of *QFD matrices* linked together by successive functions, that accomplish a common goal. The first *matrix relates customer types and customer needs*. The second matrix considers *customer needs and product features*. Another one considers *product features with feature goals*. The next matrix considers product features with *process features*. Another matrix considers process features with *process controls*, and so on. Such concatenations let the *designer become aware of all customers*, features and *processes* involved, and their *needs*.

For *the Rollout* example, one customer may be a person; one need may be becoming immunized; features may include types of vaccines; processes may include the transportation and storage of vaccines; controls may include SPC procedures for stored vaccines. Finally, *FMEA* constitutes an alternative way to analyze every element in the system. For each element, we obtain its key functions, its causes of failure and failure modes, failure effects and consequences, corrective actions, etc. Thence, we can avoid such failures, or come up with a possible plan B.

Proceeding in a systematic manner, we do not leave out any part of the system without analysis or consideration. Problems slip through, when we neglect to consider some parts of the system.

We have seen, in the previous pages and in the illustrative student PPTs, the implementation and use of some of these methods. They can be used in initial assessment, as well as in other phases of the Covid-19 analysis. For further explanation of their usage, we defer to the Bibliography.

5.0 Discussion

Our *previous Covid-19 research* dealt with *statistical modeling and analysis* of several situations (https://www.researchgate.net/publication/349008991_Commented_Summary_of_a_Year_of_Work_in_Covid-19_Statistical_Modeling). *Our current research* deals with the *application of* QE, including reliability, logistics, industrial, and operations research, *statistics-based*, *engineering methods*, *to the design, development and improvement of* health care *systems dealing with* the *Covid-19 Pandemic*. *Both* of said *approaches are complementary*, and reinforce each other.

We examine how problems were noticed in all four discussed Covid-19 systems. *Lock Downs* produced economic distress to many business owners and workers. *Re-Opening* too fast brought an increment in some community infection rate levels. *School Reopening* was slow and partial in some school districts. Finally, *Vaccine Rollout* was initially slow and poorly coordinated, and vaccine delivery, difficult to implement. *Statistics-based* engineering tools help improve them.

In addition, we have shown our graduate engineering students how to consider and solve real-life Covid-19 problems. This experience alerts them to their social, engineering responsibility, and provides them with additional fields where they can apply their engineering expertise.

Limited interaction exists between public health professionals, and reliability, quality, logistics, industrial and operations research statistically-based engineers. However, fighting the Covid-19 Pandemic requires, to become more efficient, that these two professional groups work together. Higher levels of infection, hospitalization and vaccination, require larger logistics preparation levels. Lacking cooperation, efforts can be duplicated or wasted. Thence, efficiency will be lost.

Remember again the example of the *Normandy Invasion, of June 1944*. *Generals and politicians* established *strategy*, the type and amounts of soldiers, and equipment required to win the day. But *Logistics and Operations Research engineers determined* the *support*: food, water, fuel, ammo, etc., scheduling where and when these were needed. With Covid-19, the situation is comparable.

Successfully combating Covid-19 requires near 100% efficiency. First, we want to be capable to provide help for all the people that require it, and deliver the different types of resources that the Covid-19 Pandemic includes, in the different places they are needed. For, we will not solve our own Covid problem as long as other nations continue to struggle with the Pandemic. Renewed strains of Covid-19 viruses will eventually return; and we will need to restart the entire process.

We end by signaling out *several major problems* of the four systems analyzed. *Firstly*, they were *supervised by politicians and not by* Public Health, Medical, Engineers or *technical specialists*. *Secondly,* the *Covid-19 Pandemic* question itself, *became highly politicized*. For example, entire political groups and political leaders, were identified with some Covid-19 position. For, wearing a mask (or not), vaccinating (or not), was regarded as supporting (opposing) specific candidate or party. This unfortunate circumstance complicated a situation that was quite difficult in itself.

A *final* major *problem* was *deficiency in prototyping*. Proposed *initial solutions could have been compared* and assessed directly *on physical prototypes or,* when experimentation in such were not feasible, *on simulation models*. Prototyping would have allowed selecting the most efficient solution. P*otential problems could have been detected, identified and corrected* way before final implementation. Remember *Murphy's Laws* on Technology: *if something can go wrong, it will!*

5.0 Conclusions

We derive no pleasure in raising problems that have occurred during this Pandemic. We know that the majority of those involved in this process are well-intentioned, and have tried their best. Our *objective* by raising such issues is *to alert* those involved *about techniques* that *exist*, and about *specialists* that can be *recruited*, to help them *improve system efficiency*. Covid-19 will be around for some time. There is still much work to do, and QE techniques can be very helpful. If anyone is interested in further information about such techniques, do not hesitate to contact me.

We want to *reach four audiences*: (1) *public health* professionals and researchers, (2) *medical doctors and institutions*, (3) *reliability, quality, logistics, industrial, operations research, and other statistics-based engineers,* and (4) *the public* in general.

We want to *encourage public health researchers and medical professionals to use statistics-based* engineering procedures, *undertaking joint work with quality, reliability, logistics and industrial/operations research engineers*, not only after health care systems have been designed and implemented, but also *during the time that these systems* are being *designed and prepared*.

We want to *encourage said engineers,* especially retired ones, who have the experience, financial support (their pensions), and the time to provide their assistance, *to contribute in helping with the planning, implementation and analysis* of support systems –or with writing about them.

We want to *provide illustrative examples* to subject matter and public health researchers, to government officers, and to the general public, to help them understand what engineers do, and how can engineers help improve the Covid-19 systems, thus *fostering greater collaboration*.

Finally, *this research on statistics-based engineering analysis of Covid-19 systems* can *be used as part of a biostatistics course* in a public health, or medical curriculum, or as part of an *applied modeling and analysis graduate course in an industrial and systems, or an operations research engineering department, or in an applied statistics department*.

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